

## Article

# Modeling of Prospects for the Development of Regional Renewable Energy

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**Abstract:** It has been proven that to solve the problems that arise in the combinatorial modeling of the prospects for the development of regional renewable energy, an algorithmically simple general combinatorial approach is the most appropriate option. The conceptual express method and corresponding mechanisms of the economic estimation of the efficiency of variants of the formation of regional systems of renewable energy have been suggested. These variants take into account the inflationary factors which serve as a basis of the analysis of investment and innovative projects of renewable energy sources by means of combinatorial modeling methods. To qualitatively analyze the effectiveness of the compared options, the system of existing indicators of the economic efficiency of renewable energy sources at the meso-level has been studied. The system was supplemented by informal and environmental indicators, the need for which is due to the fact that they have a significant impact on renewable energy in the region. Factors that significantly determine the effectiveness of the investment and innovation project for the introduction of renewable energy sources into the regional economy have been substantiated.

**Keywords:** renewable energy sources; regional economy; investment and innovation project; efficiency; environment



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## 1. Introduction

Rational use of renewable energy sources (RES) such as wind, solar radiation, geothermal energy and biomass is one of the essential components of sustainable development, which brings significant environmental and energy effects. The growing share of renewable energy sources in the fuel and energy balance helps to improve the efficiency of use and saving of energy raw materials, improve the environment, reduce pollution of the atmosphere and water, as well as reduce the amount of production and human activity waste.

In this regard, supporting the development of renewable energy is becoming increasingly important for almost all countries. RES can play a significant role in the energy balance of separate regions or provinces of our country, increasing their energy security. Renewable energy development is able to attract and develop additional infrastructure for the implementation of new projects and the operation of existing energy facilities. However, most importantly, the widespread introduction of RES will help solve many environmental problems that arise in the process of using traditional fuel resources.

The implementation of the regional energy policy is connected with solving the pressing problems of the functioning and development of the regional energy system.

Most of the energy problems in the regions are country-wide energy problems. That is why energy problems should be solved by the joint effort of the state and the regions. This is due to the importance and significance of the energy supply of the economy and the population of all regions of the country without exception, and the presence of powerful extensive energy supply networks (a single energy system for the supply of electricity, gas transportation and oil transportation systems, etc.).

The specifics of energy, especially regional energy, may include the fact that its products are vital for modern society; large energy volume projects are aimed at obtaining public goods and aim to solve the pressing problems of the population of entire cities and regions. The possible loss from the non-implementation of such projects often exceeds the cost needed for their implementation.

One should better assess the projects of this type, which are aimed not at achieving maximum efficiency, but at solving socio-economic problems at an acceptable technical level in an acceptable time, using the indicated costs. The content of the indicators that are used when selecting using the minimum reduced cost criterion is the same as in the case of the maximum economic effect criterion.

The study of the variants for the development of the region's fuel industries in modern conditions has its peculiarities. In contrast to the fuel and energy complex (FEC) of the country, the connections of which are considered at the macro-level, the development of energy industry objects of the region is closely connected to specific consumers of their products. It is characterized by the inclusion of the FEC enterprises in the formed technological chains of metallurgical, chemical and other industries, the changes in which are often associated with high costs and technical difficulties. Given this, it is important to consider the discreteness of possible states of objects and ways of its achievement when modeling the industries of the regional FEC.

It has already been noted that the uncertainty of the development of both the energy sector and the entire economy causes great difficulty in assessing options for the development of energy sectors. One of the practical recommendations—the conduction of the research for three hypotheses of the development of the national economy (optimistic, moderate, and pessimistic)—remains valid when studying the industries of the regional FEC. Moreover, the scenario approach, implementing this recommendation, is now gaining a wider scope of application.

The purpose of the paper is to substantiate the theoretical, methodological and methodical-practical foundations of regulation of regional innovative development based on the introduction of renewable energy under the influence of the modern economic environment.

## 2. Literature Review

The coordination of the production of energy sources and their consumption represent difficulties of a fundamental nature. If earlier studies were conducted from the position that “everything that will be needed and can be produced must be produced”, in modern conditions, economic entities are based on the principle to “produce what is profitable and what is in effective demand” [1].

If previously the models provided for the needs which were necessarily subject to the satisfaction, now there must be no such needs as they were understood before. However, if a region is interested in maintaining a certain minimum level of consumption of fuel and energy resources (FER) in its territory (to prevent, for example, aggravation of the socio-economic situation), it must either buy them at market prices or compensate the producer for possible losses [2].

But relations with external consumers must be developed on a commercial basis. Therefore, in any case, there must be a preliminary analysis of the range of potential consumers of products of the regional fuel and energy complex (FEC), and related developments can be used almost unchanged [3].

The issue of financing the construction and operation of energy facilities, which is so relevant today, has not been studied at all before. It was reasonably believed that if a decision on construction has already been made, the money for it will be allocated from the budget [4].

Now one of the most important components of any investment project is a detailed study of the issue of possible sources of financing such as bank loans, funds from the corporatization of the facility involving future consumers of its products, and public investments. Such studies require a special block in the models, which must be used after the pre-selection of options [5].

It seems that in modern conditions in the study of prospects for the development of regional FEC there must be more widely used simulation modeling and methods of intersectoral balance, in addition to combinatorial modeling [6].

Simulation models and programs must have the flexibility that provides the researcher with a high degree of freedom in the choice of tools and methods in solving emerging problems. Among the methods of intersectoral balance, the best balances are the ones with in-kind and specific indicators. In this regard, it seems to be an interesting idea to make out an intersectoral energy balance and use it as a base for evaluating the effectiveness of investment projects [7].

The tools for modeling the economy and its systems have been actively developed in the last half of the century due to the appearance of ECMs and the development of methods for solving modernization problems [8].

The simplex method is still widely used, which allows for solving the problem of linear programming with a large number of variables in a relatively short time. However, researchers who use this method are forced to “adjust” their models to it replacing discrete quantities with continuous ones, nonlinear relationships with linear ones, which reduces the value of models and studies based on it [9].

On the other hand, the possibility to solve problems with thousands of variables has led to the creation of models of the economy and its industries with an unreasonably high degree of detail, attempts to “comprehend the immeasurable”, which was combined with the determinism of the models [10]. These features were inherent in the models at the initial stage of development of modernization methods, which were also manifested in the models designed for the purposes of medium- and long-term forecasting. In order to also take into account the objectively existing uncertainty in the development of sectors of the economy, studies based on deterministic models were conducted for several hypotheses of economic development.

Relationships between the models included in the system reflect the real interaction of industries, economic systems with different degrees of adequacy [11,12]. Special rules and procedures are developed to coordinate decisions and forecasts obtained when working with separate models or at different levels. Since a study on the prospects of economic development is a creative process that requires understanding the obtained results and periodic return to the starting point of the study with new knowledge and approaches (the need for this in modern conditions is more obvious than ever), the need for such modifications often arises [13].

From the above-given data, it follows that a researcher must have not a ready, complete and stable in its forms model and software complex, but a set of different tools for the timely development of modifications and projects aimed at multiple research cycles taking into account the emergence of new factors, the detection of hidden directions, the demonstration of the influence of previously unfamiliar conditions or factors that were considered insignificant [14].

Such a set aimed at a specific area of research must help to create models that most fully take into account the characteristics of the object under study and include or use existing databases and knowledge, expert systems that contribute to the understanding and interpretation of obtained results [15].

As mentioned above, it is impossible to find a solution that would ensure the highest efficiency of the FEC industries in all possible situations in the future. Simply, solving the modernization problem is not enough for this, especially since energy is characterized by the proximity of the economic efficiency of technically different solutions. It is necessary to have a set of suboptimal (i.e., close to optimal) options for the main scenarios of economic development [16].

By analyzing them, you can identify the objects needed in all scenarios, the objects, the emergence and development of which will be determined by the development of the situation, will be clarified in the future, and, finally, the objects that are virtually unnecessary [17].

So, the simulation can take into account the objectively inevitable multi-stage decision-making process regarding energy development. This circumstance dictates the need for methods to assess the combination (set) of options for the development of separate objects of the industry and to select suboptimal combinations. The object of the model here means either a single large enterprise, deposit or group of homogeneous smaller objects [18].

Nevertheless, the works of the mentioned authors primarily focused on the study of the development of specific converters of energy or the application of converters of renewable energy in the small energy sector for local or national energy supply and practically did not consider the use of renewable energy sources of individual regions. Due to this, there is almost no methodology for studying the state and the perspectives of renewable energy source development at a meso-level.

The models of the RES object systems and assessment of the RES economic efficiency at a level of regions require considerable and immediate improvements. It is also important to develop the criteria for the selection of rational technologies and volumes suitable for attracting the renewable energy sector at the meso-level.

The regions do not have innovative strategies for managing the development of renewable energy, its effective development, and its use. All this may lead to significant economic losses and a lag in the energy industry and even lead to the loss of the country's economic security in the future. Given this, there is an urgent need for modification of the methodology and establishment of the fundamentally new effective mechanisms for regulating the regional innovative development through the introduction of renewable energy, which has led to the choice of the research topic.

### 3. Methodology

To model the perspectives for the development of sectors of the regional FEC, one uses an approach grounding on the ideology of discrete dynamic programming. The approach foundation serves as a visual representation of the development of objects, which form a modelled system in the form of a directed graph, the nodes of which correspond to the possible states of the object at certain moments, and the connections characterize the permissibility of transitions from one state to another. Objects refer to the structural units of a modelled system, which are considered as a single entity. It can be enterprises or a combination of the energy sector enterprises of the same type, enterprises-energy resources consumers or entire categories of consumers. The formation and analysis of ways for the development of the system is carried out through the study of various states and transitions of individual objects and their combinations. Therefore, this approach obtained the name of combinatorial modeling.

The combinatorial approach can be supplemented by other modeling methods. Along with discrete alternatives for one indicator, it is allowed to use continuous sets upon other parameters. In mathematical form, the combinatorial models are given in the form of modernization problems with integer variables, which is a traditional method of discreteness introduction.

Numerous scientific studies pointed out the danger of subjectivity in assessing the prospects of energy, which is characterized by the financial similarity of numerous technically different projects. To avoid its negative effect, one offered to hold an analysis of the country's energy perspectives at the macro-level, highlighting the main fuel bases and industries. Nevertheless, when transferring this approach to the regional level, one faces the need for studying the options of individual fuel and energy companies, the largest consumers of their products. Therefore, this work proposes an approach to the multivariable analysis of the perspectives for regional energy, grounding on combinatorial modeling and modern computing capabilities. Together with the procedure for the formation, assessment, and selection of variants of the system under study, it provides for the high-quality formation of classical variant analysis as it guarantees the completeness and comprehensiveness of consideration and assessment of the entire spectrum of potential for the construction of energy concepts in the region.

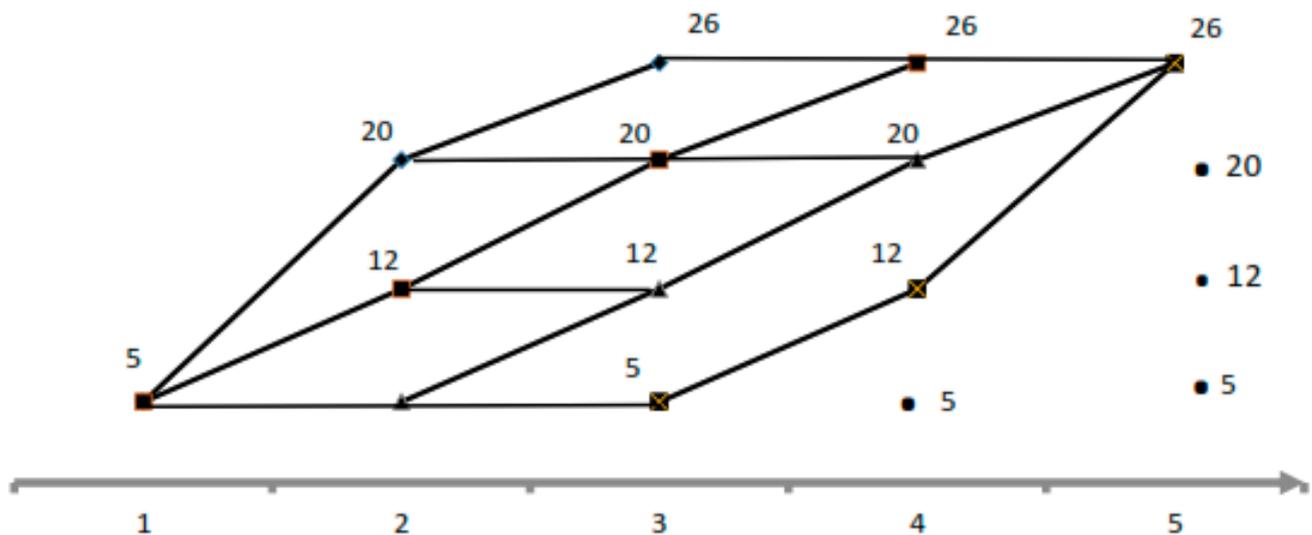
The combinatorial approach allows one to:

- (1) consider the discreteness when modeling: the results of significant scientific and technical problems solution; adoption or non-adoption of principled decisions on the development of new sources, which do not belong to the area of competence of the region; construction of developed fuel transport lines, power lines, etc.;
- (2) adequately reflect the discreteness and sequence of input of individual objects, their queues and parts in the models;
- (3) describe not only ways of developing objects of the system under study but the main possibilities of change of the external environment of the system—energy resources consumption, the general economic situation, and ways of solving important scientific, technical, and social problems.

The modeling of the listed factors is carried out based on a single methodological and algorithmic basis, which enables the possibility to introduce new objects, schemes, and factors into the model without significant complication. These and the conditions mentioned above make combinatorial forecasting the primary method for the search of opportunities for forming the region's energy concepts.

In the course of modeling and analysis from the facility to the entire FEC, one considers the discreteness of variants of the objects, industries, and complex development, the uncertainty of the forecasting information, and the availability of multiple stages in the process of making decisions on the development of the renewable energy sector. If necessary, one can carry out the analysis considering several criteria of the development of objects, systems, and industries of the energy sector. The effect of the general economic situation on the perspectives of the region's FEC development is considered when developing scenarios of external conditions, coordinating levels of production, and consuming energy resources.

The starting point of the analysis in the application of combinatorial forecasting methods is the presentation of the main opportunities (alternatives) for the development of the object in the form of options, which are formed by highlighting the main stages of the technical implementation of construction, reconstruction or closure projects. The dynamics of the object development is described by the sequence of its states at fixed points in time. From the economic point of view, such discretization of the process is justified, as the return is possible only from the technologically complete section of the object. For clarity, it is convenient to present the options for dynamic object development in the form of a graph (chart), the nodes of which correspond to the states of the object (stages of project implementation), and arcs—transitions from one state to another. The allocation of time periods does not have to be carried out evenly. It is dictated by the interests of the study (Figure 1).



**Figure 1.** Conventional wind farm construction options. Notes: Project implementation conditions (process axis): 1—transportation; 2—power supply; 3—preparation; 4—maintenance; 5—financial assurance capacities.

It is assumed that during the preparation of the wind farm construction project it was found that under the conditions of transport, energy supply, installation and operation, it is more rational to conduct construction in sequential groups of 5, 7, 8 and 6 wind stations (i.e., the total number of wind stations will be 5, 12, 20 and 26). Opportunities for financial support, in turn, dictate the different rates of installation and connection of wind stations to power lines, which is ultimately expressed by the presence of 7 options for the development of this wind farm.

Having thus described the options for the development of the industry facilities, we can begin to analyze their totality to develop the main options (alternatives) for the development of the FEC sector as a whole, i.e., options for a higher hierarchical level. When considering and evaluating the set of options for the components of the industry facilities, it is necessary to take into account all significant systemic constraints for the regional FEC. Some of the constraints can be formalized and written in the form of balance equations or inequalities of volume or rate indicators, and some of them in the form of logical conditions for the compatibility of certain projects, the sequence of activities. As a rule, the vast majority of combinations of options for the development of facilities do not satisfy such a system of constraints.

The rest of the combination of options allowed by industry constraints are analyzed in terms of efficiency in accordance with the criteria adopted in the study. The predominance of any combination of options by all criteria is unattainable as the real systems of criteria are contradictory.

For example, the requirements of profitability are in conflict with environmental factors, requirements of safety and reliability; financial risk reduction requirements are in conflict with the desire to reduce project costs. In such situations in studies, they use:

- (1) principle of Pareto optimality;
- (2) convolution of criteria, i.e., their reduction to any one or a new complex criterion obtained by summing up all the criteria with a weighing coefficient depending on their significance. As a special case of this approach, you can consider the choice of any criterion as a determinant and performing calculations using the model with one of these criteria (i.e., its weight is taken equal to one, and all others zero);
- (3) prioritization of the set of criteria and sequential optimization for each of them;
- (4) framework of fuzzy set theory, which allows for using binary (pair) relations of domination to rank directly not matched options by domination and evaluate them by priority.

It is important to note that whatever method is used to solve the problem, the solution obtained will be reasonable if it is Pareto optimal. Otherwise, it can be improved by one of the criteria without deteriorating by others. At any weighing coefficients, as a result of solving the problem (Equation (1)):

$$\sum_{i=0}^n a_i \cdot g_i(y) \rightarrow \min_{y \in Y}, \quad (1)$$

We obtain one of Pareto optimal problem solutions with target functions (Equation (2)):

$$g_i(y) \rightarrow \min_{y \in Y}, \quad (2)$$

where  $Y$  is a set of acceptable solutions. By varying weighing coefficients  $a_i$ , you can obtain a set of all Pareto optimal solutions. On the basis of this property, it is possible to carry out economic interpretation of various criteria. Suppose that in the considered set of target functions (2)  $g_0$  is a cost one. As is known, multiplication by a positive value does not change the optimal solution. Therefore, the problem is Equation (3):

$$g_0(y) + \sum_{i=0}^n w_i \cdot g_i(y) \rightarrow \min_{y \in Y}, \quad (3)$$

where  $w_i = a_i/a_{i0}$  is similar to the problem (1) and also has an optimal solution. In the formula (3), all components of the target function have a cost dimension. Therefore, the values  $w_i$  are the factors of conversion of  $g_i(y)$  into the cost form. For example, if  $g_i(y)$  is an indicator of the amount of environmental pollution, then  $w_i$  is interpreted as a specific damage from this type of pollution. Thus, any Pareto optimal solution can be represented as a solution of the modernization problem with one cost criterion, that of the maximum economic effect or minimum cost.

The search for Pareto optimal solutions of discrete problems fits well into the structure of combinatorial modeling. It is possible to illustrate the method of solving similar problems using the example of a discrete two criteria model where it is required to maximize two indicators,  $\{R_1, R_2\} \rightarrow \max$  with some restrictions to the variants of the analyzed system. The set of Pareto optimal solutions is a set of points—"angles" of a stepped polyline.

It is obtained using the method of successive restrictions replacing a two-criteria problem with a series of single-criterion ones. At first, the problem is solved where only the first indicator is maximized, with restrictions of the initial problem.

To solve problems of choosing the optimal combination of options for the development of objects included in some system, it is advisable to consider the famous techniques and mathematical methods, which in the most general form can be written as Equation (4):

$$\begin{cases} R(x, y, c, s, z, d, p \dots) \rightarrow \max(\min) \\ V(x, y, c, s, z, d, p \dots) > 0 \end{cases}, \quad (4)$$

In this case,  $R$  and  $V$  are vector functions of criteria and restrictions. Of the above specific parameters, the most common are:

$x, y$ —Boolean variables, indicators of the use of options of objects and consumers, accordingly;

$c$ —energy resource price vector (in dynamics);

$s$ —costs according to options for the development of objects;

$z$ —the effectiveness of options to meet consumer needs;

$d, p$ —extraction and consumption of energy resources.

These techniques and methods can be combined into three large groups.

1. Reduction, i.e., reducing to linear programming problems by replacing the requirement of Boolean variables  $x, y$  by a constraint— $0 < x < 1, 0 < y < 1$ —and solving the obtained problem using the simplex method or any other method. A solution found this

way has a significant disadvantage—it is a non-target one. In other words, it characterizes not a certain type of production or use, but a complex of alternatives for each of the objects in a certain ratio. The attempts to correct this disadvantage, for example, by choosing the option with the largest “specific weight”, lead to a solution with doubtful optimality; at the same time, as a rule, constraints are broken. However, in practice, this is probably the easiest way.

2. The use of combinatorial technologies shows the exact implementation of the ideas of combinatorial forecasting—control over the acceptability of combinations of options in the process of absolute or reduced consideration of basic, clear instructions for search. These methods provide the best integer-valued solution. For them, the non-linearity of a goal-oriented function and constraints cannot be considered an obstacle. The potential to solve multi-criteria problems or to perform synchronous optimization according to many aspects, to select not only rational but also all suboptimal solutions without exception reveals additional abilities in conducting a study. The disadvantage of this approach is the exponential increase in the number of combinations of options, and especially with the increase in the number of considered objects. The current available computing equipment makes it possible to use this kind of approach to the system now, and such capabilities will only grow over time. However, at the same time, a huge amount of time will be offset by reducing the period for collection and debugging projects for a computer, because they are simple and clear.

3. To date, a large number of algorithms have been developed to address the issues of integer, Boolean and inhomogeneous programming. Due to taking into account the distinctive features of the issues to be solved, they mitigate the interdependence of the calculated activity on the number of alternatives, but because of this, a large number of positive properties characteristic of more general combinatorial methods are also lost. Developing and configuring programs according to these methods usually takes a lot of time. However, the situation changes if there are ready and tested software modules.

Here is how one considers the task of choosing the most efficient distribution of limited investment resources (Equation (5)):

$$\sum_{i=1}^R \sum_{j=1}^{U_i} f_{ij} y_{ij} \rightarrow \max, \quad (5)$$

with restrictions on the total amount of investment (Equation (6)):

$$\sum_{i=1}^R \sum_{j=1}^{U_i} s_{ij}^t y_{ij} < d^t, \quad (6)$$

and restrictions, which mean choosing one option for each project Equation (7):

$$\sum_{j=1}^{U_i} y_{ij} = 1, \quad (7)$$

This model considers investment projects  $R$  over a period of time divided into  $m$  stages. The 1st project has  $U_i$  implementation options: the option  $j$  of the project  $i$  has an efficiency  $f_{ij}$  with the required investments  $s_{ij}^t$  for the period  $t$  and the total amount of available investments  $d^t$  for the same period

Below, we provide the methodology for the case when there is retrospective information on the factors that determine the economic efficiency of the RES project, for example, the selected company that invests its own and attracted funds in the production of goods that are characterized by steady demand; this is the kind of product produced by many FEC enterprises. The efficiency of the project implementation depends on both factors controlled by the company’s management (expenses, investments, profit) and external

factors, including taxes and additional payments, the volume of attracted capital and the volume of sales.

- (1) One builds a mathematical model of the investment project efficiency. With consideration of factor selection, it has the following form:

$$\begin{cases} B_t = m_{10} + m_{11} \times h_t + o_t^1 \\ I_t = m_{20} + m_{21} \times h_t - o_t^2 \\ l = h_t - B_t - I_t \end{cases}, \quad (8)$$

Here, one mentioned the controlled factors:  $B_t$ —expenditures,  $I_t$ —investments,  $l$ —profit (undistributed); random (external) factors:  $o_t^1$ —taxes and additional payments;  $o_t^2$ —attracted capital;  $h_t$ —the volume of sales;  $m_{10}, m_{11}, m_{20}, m_{21}$ —unknown coefficients.

- (2) Using the Method of Least Squares based on the retrospective information on the factors (Appendix A), one finds the coefficients of the model (8), after which it takes the following form:

$$\begin{cases} B_t = -2.71 + 0.7351 \times h_t + o_t^1 \\ I_t = 0.0644 + 0.1681 \times h_t - o_t^2 \\ l = h_t - B_t - I_t \end{cases}, \quad (9)$$

- (3) The obtained system of equations is solved with regard to the controlled factors, as a result of which they are all expressed through random variables:

$$\begin{cases} B_t = -2.71 + o_t^1 + 0.7351 \times h_t \\ I_t = 0.0644 - o_t^2 + 0.1681 \times h_t \\ l = 2.6456 - o_t^1 + o_t^2 + 0.0968 \times h_t \end{cases}, \quad (10)$$

- (4) Using this model, one carries out probabilistic calculations. For random factors, their possible values for the perspective with probabilities of implementation are determined using the expert way.

#### 4. Results and Discussion

The use of RES has a range of peculiarities when implementing projects of different energy sources. Thus, intermittency in the supply of energy from alternative sources contributes to an increase in costs. There is a belief that interruptions can be handled through small changes, such as time pricing, “smart” grids, and blackouts for some previously selected industrial consumers if there is not enough electricity for everyone.

This approach may theoretically take place if the system grounds on the use of fossil fuel and atom energy, to which one also attaches the use of a small percentage of renewable energy sources. The situation changes depending on the expansion of the network with new sources of renewable energy.

After the electrical grid is expanded with even a small percentage of solar power, one needs batteries to smooth out the rapid transition that happens at the end of the day when workers come back home for dinner, when the sun has already settled. One should also consider power outages that occur due to the shutdown of wind turbines during storms.

There are also many other problems. Intense storms can disrupt the power supply for several days at any time of the year. If the system works only on renewable energy sources, it is necessary to have a backup battery that would have a reserve for at least three days.

As of today, the number of batteries is too small to provide a three-day reserve supply for the power supply of the entire world. If the global economy is going to use renewable energy, electricity consumption will significantly increase compared to the relevant level, which will complicate the process of storage of a three-day reserve supply of electricity.

There is a more complex problem than the storage of a three-day energy supply. It is a need for seasonal storage if renewable energy sources are used more or less widely.

Here are some of the main reasons for higher expenditures on wind and solar power transmission.

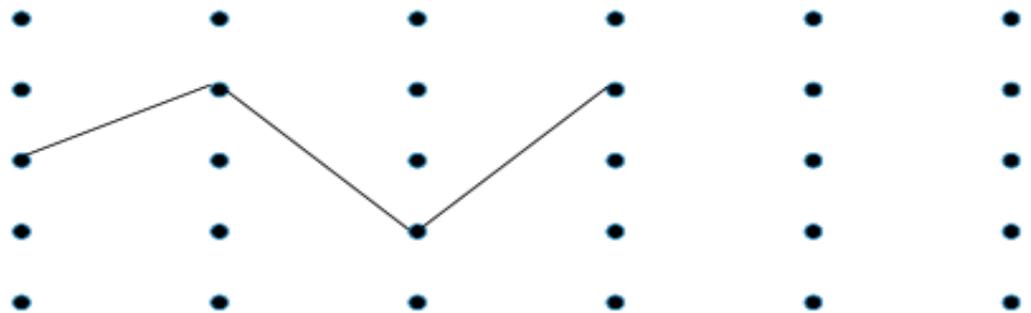
One should build disproportionately more lines for wind and solar energy since power lines need to be scaled to the maximum power, not average power. Power generation from wind is usually available from 25% to 35% of the time; power generation from the sun is usually available from 10% to 25% of the time.

As a rule, the distance between the place where renewable energy is used and where it is consumed can be much bigger compared to traditional production.

Renewable electricity and installed auxiliary equipment do not possess the same level of control over the aspects of the power grid (current power, amplitude, etc.), in contrast to a fossil fuel power plant. Therefore, one should introduce changes to the energy transmission system, which require additional infrastructure and, thus, new expenditures.

All these reasons should be considered when modeling the perspectives for the development of the regional renewable energy sector.

In the chart (Figure 2) illustrating the operation of the algorithm, the number of projects  $R = 6$  and the number of options for all projects  $U_i = 5$ . The currently considered combination of options is marked by a line connecting the current options of each of the projects. The chart shows a combination of the 3rd option of the 1st project, the 2nd option of the 2nd project, the 4th option of the 3rd project and the 2nd option of the 4th project. The 5th and the 6th projects are not presented (in this example they will not affect the operation of the algorithm) in this combination.



**Figure 2.** Combination of options of the considered projects of renewable energy sources (3rd option of the 1st project, 2nd option of the 2nd project).

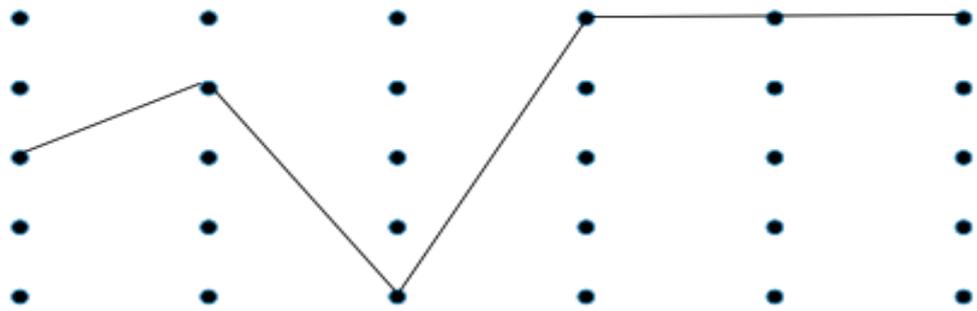
It may be assumed that the review begins with a combination consisting of the first options of projects and is conducted consistently, and the bigger the number of the project (the more it is to the right in the chart), the faster its options change.

For example, if the combination in Figure 2 is unacceptable (i.e., requires too much investment), it is clear that all combinations in which the 4th project has the 2nd or subsequent options will be unacceptable.

Therefore, one can skip them and consider and check the combination presented in Figure 3, in which the 1st and 2nd projects have the same options (because when you review them, the options change last), in the 3rd project the next, 5th option is taken, and in the 4th and other projects the first options.

Therefore, there is no need to test 74 combinations of options. The effectiveness of this technique is strongly dependent on the task, and the gain in time of calculation using the programs can vary significantly.

Using the methods of combinatorial modeling, which are accompanied by the large-scale enumeration of possibilities, it becomes quite useful to use the methods of variant express evaluation of efficiency and acceptability. In the studies of renewable energy sources (RES) in the economy, there often appears to be a need to assess the parameters of the profitability of projects (and their options), to activate credit, with repayment from future income. Naturally, inflation factors will sufficiently influence the solution of such problems. Many RES projects with a long investment cycle can be influenced by inflation factors when assessing option efficiencies.



**Figure 3.** The next combination of renewable energy sources (RES) project options in case of the unacceptability of the previous one.

This means that it is possible to find the limits of parametric changes of variants, where the necessary efficiency threshold is preserved, with the help of quick variant estimation using specific inflation indicators. This will certainly have a positive impact on the success of the use of combinatorial modeling techniques in the economic studies of including RES in the energy balance of the region. Also, it should be noted that this technique can be used both by organizations in defining the factors of the acceptability of lending conditions or benefits from deposit investment of funds, opportunities to accumulate own funds to implement RES investment and innovation projects and by banking institutions in defining the usefulness of inclusion in their balance resources from loans.

It is tempting to use a method of constructing risk profiles that differs in clarity and a single approach. In combination with combinatorial prediction, this way, under the condition of the required data availability (retrospective short-term series, monitoring, expert assessments) and without ignoring more or less significant cases of random factors implementation, one can give a comprehensive final probabilistic assessment of the efficiency of the project on the reliability of achieving results of a certain level, which makes it possible to carry out or reject it. What is important here is that, in this way, one considers both discrete conditions and conditions, the characteristics of which all have chances to allow all types of values out from a specific spectrum (approximate them using two or three alternatives). Without claiming universality, this method is adequate for many promising energy projects in the energy sector, including small and renewable energy projects.

Here are the main hypotheses used when applying the desired method:

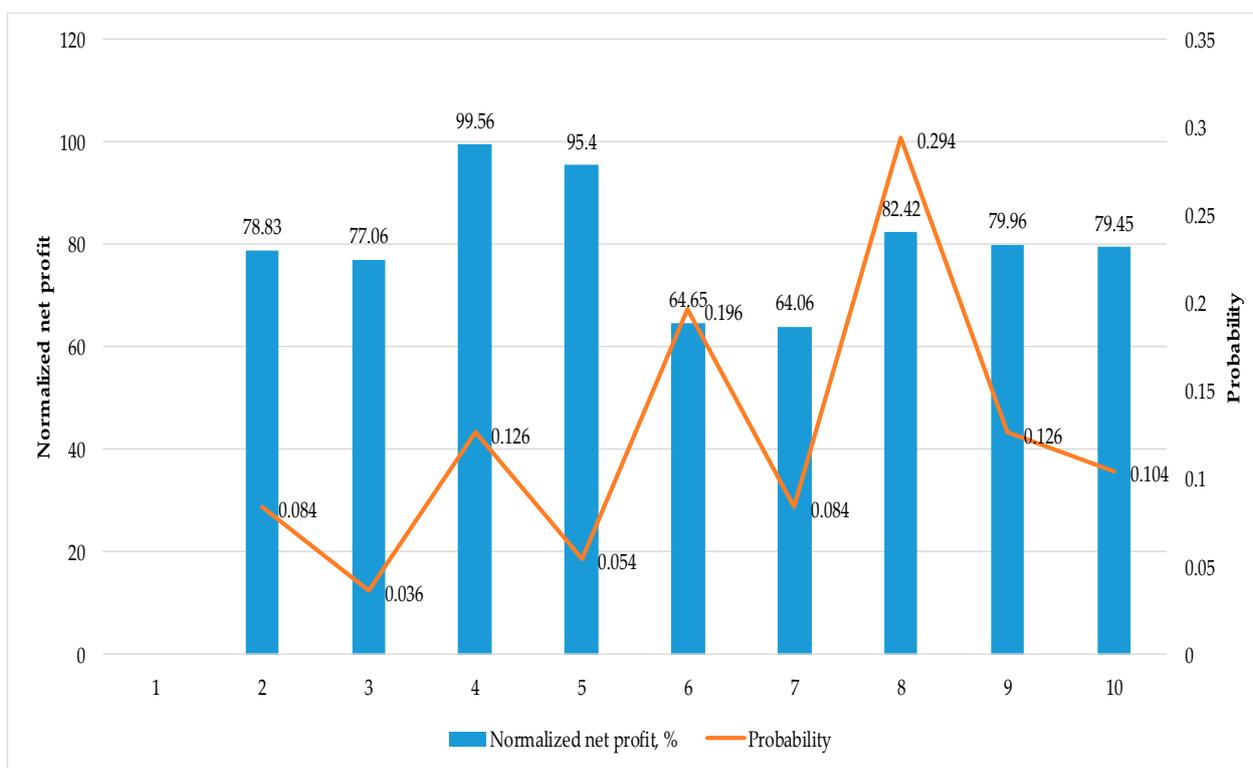
- (1) The threat of project implementation is clearly structured into single main circumstances, which are not sufficiently interdependent from each other (in the case when several conditions are in close connection, they should be combined into one);
- (2) Any of such risk moments is explained as an incorrect understanding of its parameter;
- (3) For any parameter, there is a probability to determine probabilities of acceptance of these or other values by competent expert evaluation.

When processing the results of calculations, the main role is given to the construction of cumulative risk profiles of the efficiency indicators of the RES investment project by the model (8–10). Information for construction is collected in Table 1.

Figure 4 demonstrates a graphic interpretation of efficiency indicators of RES investment projects and probability by indicators “Normalized net profit, %” and “Probability.” Achieving a maximum profit of USD 214.1 million is possible with a probability of 0.054. As follows from the above data, the combination of minimum taxes and maximum sales and borrowed funds is most favorable for the profitability of the project just with such probability.

**Table 1.** Efficiency indicators of RES investment projects and the probability of their implementation.

Total Investments, mln USD	Total Profit, mln USD		Normalized Net Profit, %	Probability
	Before Return of Borrowed Funds	Net (Return Period Is 4 Years)		
162.2	177.6	127.9	78.83	0.084
177.0	186.1	136.4	77.06	0.036
134.2	205.6	133.6	99.56	0.126
149.0	214.1	142.1	95.40	0.054
162.2	154.6	104.9	64.65	0.196
177.0	163.1	113.4	64.06	0.084
134.2	182.6	110.6	82.42	0.294
149.0	191.1	119.1	79.96	0.126
149.8	180.9	117.8	79.45	0.104

**Figure 4.** Efficiency indicators of RES investment projects and probability by indicators “Normalized net profit, %” and “Probability”.

For net profit, the analogous value amounts to USD 113.4 million, and for normalized net profit 80%. These values differ from the mathematical expectation of indicators, which is associated with an uneven distribution of performance indicators on the probability scale. In the given example, there are three random factors, each of which can take two values. With an increase in the number, one considers random factors and their values; as a rule, one also observes an increase in the unevenness of the graph. The proposed methodology, in contrast to averaged values, enables the possibility to notice and consider differences in the distribution of indicators' values according to their probability. By changing the levels or probability of implementation of external or controlled factors, it is possible to assess

the degree of their impact on the effectiveness of the project, the ability of the company to minimize the possible negative consequences of certain investment decisions itself.

Different energy technologies have different effects on the environment. Based on the analysis of various sources and expert surveys, such an impact can be represented as follows (Table 2).

**Table 2.** Qualitative environmental impact assessment of various energy technologies (in scores).

Energy Technologies	Global Warming		Acidic Emissions		Human Health and Safety	Heavy Metals	Disasters	Waste Disposal	Landscape Change	Noise	Soil Needs
	CO <sub>2</sub>	CH <sub>4</sub>	SO <sub>2</sub>	NO <sub>x</sub>							
HPP	0	0	0	0	2	0	4	0	6	0	6
WPP	0	0	0	0	2	0	0	0	6	2	2
TPP and CHPP, biomass-fired	0	6	2	2	4	2	0	2	2	0	6
Solar collectors	0	0	0	0	2	0	0	0	0	0	0
Photoelectric generators	0	0	0	0	2	4	0	2	2	0	2
Tidal power plants	0	0	0	0	2	0	2	0	6	0	2
Geothermal stations	2	2	2	2	4	2	0	4	2	2	4
Wave power plants	0	0	0	0	2	0	2	0	2	0	0
CPP and CHPP, coal-fired	8	4	8	8	4	4	2	4	4	2	6
CPP and CHPP, fuel oil-fired	8	2	8	8	4	2	4	2	2	0	2
CPP and CHPP, gas-fired	8	6	2	2	4	0	4	0	2	0	2
NPP	2	0	2	2	4	4	6	6	4	0	6

**Notes:** HPP—hydropower plants; WPP—wind power plants; TPP—thermal power plants; CHPP—combined heat and power plant; CPP—solid fuel combustion appliances; NPP—nuclear power plants.

When electricity is generated by renewable energy facilities, energy coming from adjacent energy systems is displaced. Furthermore, if the fuelless technique is used, the damage to the environment is zero.

In the operation of the fuel scheme (fertilizer, wood residues, alkalis, biogas, etc.), there is a role of negative impact on the environment caused by burning local fuel to produce electricity and additional emissions of oxides of sulfur, nitrogen and carbon dioxide into the atmosphere.

In the production of thermal energy by renewable energy facilities, regional fuel displaces foreign fuel (oil product, anthracite, natural gas). In this case, the environmental result from the introduction of renewable energy will be positive.

Our methodical approach to assessing the economic efficiency of RES is based on the comparison of technical and economic characteristics of these sources with the corresponding characteristics of other possible sources of electricity and heat. At the same time, the comparison is made using the efficiency index, by the total expenses for RES and thermal power plants, which includes both capital investments and annual costs, taking into account the environmental component, as well as the return on capital invested.

Evaluation of projected costs and results in the process of determining the effectiveness of the investment project takes place within the calculation period, which can be defined by determining the weighted average service life of key process equipment.

To simplify the procedure for selecting the most effective option, we propose to use the most significant (for the regional economy) indicator, consisting of a set of parameters.

One suggests options assessment according to technical and economic criteria that reflect the environmental, social, political, strategic and other components.

It is proposed to calculate the indicators in the following sequence:

1. The average energy tariff in the energy system of the region in which it is necessary to enter new capacities is defined. It is advisable to adopt an average energy tariff throughout the energy system to ensure the competitiveness of installations or systems introduced.

2. The optimal type of installation or system is defined by process indicators (temperature, pressure, consumables, efficiency, equipment load factor, energy production, material consumption, environmental characteristics, etc.).

3. The specific costs of energy production for this energy system are calculated and those options are selected in which this indicator is lower than the average tariff.

4. The total costs of all components, which are part of this system and affect the production of the required amount of energy, are defined. It would be better to minimize this indicator.

5. The total flow of payments for the billing period is defined taking into account discounting.

6. The efficiency index is calculated and a graph of changes in this indicator for the billing period or life cycle of the energy system or a separate facility is plotted, if the facility operates independently. We propose to take the maximum total value of this indicator for the billing period as the main factor in defining the efficiency of energy facilities.

7. The need for additional financing is defined (project cost, production assets, risk capital).

8. The internal rate of return and the payback period of the invested capital is calculated.

In our methodical approach, if the energy facility is owned by consumers, it is proposed to define the efficiency of the investment project by a cost characteristic (provided equal results over the years). From the position of a consumer, there appears to be a need to choose the cheapest and most stable option from the competing ones to cover existing needs. This can be done in the following areas of the proposed supply options:

- (1) The purchase of energy at tariffs from various energy sources;
- (2) The purchase of a power plant running on fossil fuels;
- (3) The construction or purchase of a power plant (or a complex of plants) operating on renewable energy resources;
- (4) The construction of an integrated energy facility, which uses both non-renewable and renewable energy resources.

From the position of an energy facility, which is part of the energy complex of the region, the comparable options should be reduced to the same production effect (covering the same energy needs with the lowest costs and maximum return on investment).

Furthermore, in this case it is necessary to take into account not only the costs of an energy producer (a power plant) but also the costs of a power system associated with the transfer of energy products to consumers through electricity and heat networks, as well as changes in the technical and economic performance of other power plants included in the energy complex of the region.

To assess the effectiveness of the investment project, we propose to conduct situational calculations using a scenario approach while determining the stability of the capital project to changes in external conditions and characteristics of the project itself. This method makes it possible to establish the basic, in terms of the sustainability of the project, characteristics of the initial data, and also to consider their maximum allowable, in terms of financial performance, values. Thus, the full period of the project existence is covered, and not the individual stages of its current cycle.

The conditions that vary during the review can be divided into two main categories: those that have a significant impact on the amount of revenues and those that have a significant impact on the amount of costs.

As factors of variations, we obtain: characteristics of inflation; the material scale of sales; the cost of the product and the direction of its change; unstable costs, as well as the direction of their transformation; stable costs and direction of their transformation; the required amount of investment; price of loan capital (interest on loans, discount rate).

These conditions directly affect the size of revenues and expenditures. Moreover, there are conditions that indirectly affect both the amount of revenues and expenditures. These include “temporary” circumstances, which are especially important in situations of inflation: duration of construction and commissioning; the duration of the scientific and technical cycle of product production; the period spent on the sale of the product; period of suspension of payments.

According to the level of influence of conditions on the value of the aspect, they can be conveniently divided into three categories of susceptibility: high, medium, and low. In order to make the right decision, the degree of reliability and accuracy of monitoring, the reliability of the initial data, which can also be assessed as large, medium and low, is also of great importance.

As a result of consideration of susceptibility, it is necessary not only to define more precisely those conditions, which in the maximum degree have a big influence on characteristics of the productivity of the project, but also to mark criteria according to the elimination of their negative influence.

The task of analysis can be complicated, and the results can be more significant, given the presence of relationships between different factors. The obtained information can be used to define the optimal or most likely relationship between product price and sales.

Scenarios must be made taking into account not separate factors, but their combination. Usually, one considers three scenarios: optimistic, pessimistic and normal.

This type of uncertainty study makes it possible to establish the level of resilience of an RES implementation project in the region to the potential negative impact of external conditions.

Having made a system of the above criteria and taking into account the factors that define and significantly influence the choice of the energy facility, it is necessary for the designer to identify the most significant ones. These conditions will allow for defining the most effective areas of development for regional energy systems and will serve as a driver for the introduction of renewable energy sources.

## 5. Conclusions

It has been proven that to solve the problems that arise in the combinatorial modeling of the prospects for the development of regional renewable energy, an algorithmically simple general combinatorial approach is the most appropriate option. The conceptual express method and the corresponding mechanisms of the economic estimation of the efficiency of variants of the formation of regional systems of renewable energy taking into account the inflation factors, which act as a basis of the analysis of RES investment and innovative projects using combinatorial modeling methods, have been proposed.

A method for establishing the optimal combination of efficiency factors and risks of RES investment and innovation projects in modern market conditions taking into account the high degree of uncertainty in the development of renewable energy systems in the region has been developed. The proposed method allows one to define and take into account the differences in the distribution of values of indicators according to their probability. By changing the levels or probability of the implementation of external or controlled factors, it is possible to assess the degree of their impact on project efficiency and the ability to minimize the negative consequences of certain investment decisions.

The method allowing one to harmonize the development of components of a renewable energy system of a region with minimum deviations from basic variants has been proposed. The scope of this method is to adjust the options for the development of RES in the region taking into account system constraints, as well as the coordination of prospects for the economic development of the region. Based on the study of the computational efficiency of algorithms of the method of internal points related to the type of design

algorithms, their optimal modifications in terms of efficiency for the purposes of analyzing the possibilities of economic development of renewable energy at the meso-level have been proposed.

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## Appendix A

**Table A1.** The source information for the model of investment project assessment in the system of indicators of risk-efficiency (retrospective information).

$t$	$B_t$	$I_t$	$l$	$h_t$
1	40	10	7	57
2	41	10	7	58
3	41	10	8	59
4	42	9	8	59
5	44	11	8	63
6	45	10	9	64
7	46	10	10	66
8	48	12	10	70
9	50	12	11	73
10	53	13	10	76
11	56	15	11	82
12	59	16	11	86
13	60	15	13	88
14	63	16	13	92
15	66	17	12	95
16	67	15	13	95
17	69	17	11	97
18	73	19	11	103
19	77	21	11	109
20	76	18	14	108
21	77	14	15	106
22	82	17	14	113
23	86	20	12	118
24	89	21	14	124

**Table A2.** The source information for the model of investment project assessment in the system of indicators of risk-efficiency (forecasting information).

t	$\sigma_t^1$		$\sigma_t^2$		$h_t$	
	min	max	min	max	min	max
1	3	5	5	6	45	50
2	3	5	5	7	48	54
3	3	5	5	7	50	58
4	3	6	6	8	54	63
5	4	6	6	9	56	66
6	4	6	6	9	58	70
7	4	7	6	10	61	73
8	4	7	7	10	64	78
9	5	7	7	11	67	83
10	5	7	8	12	70	88

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